Residential Central Air-Conditioner, Small Duct, High Velocity (SDHV) Systems Standards Rulemaking

Life-Cycle Cost Analysis

Draft Report for Review

Prepared for:

Building Technology Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Prepared by:

Lawrence Berkeley National Laboratory
Energy Analysis Department
1 Cyclotron Road
MS 90-4000
Berkeley, CA 94720

November 26, 2002

TABLES

FIGURES

SMALL DUCT, HIGH VELOCITY LIFE-CYCLE COST ANALYSIS

1.1 INTRODUCTION

The life-cycle cost (LCC) analysis for small duct, high velocity (SDHV) products was conducted with the same spreadsheet model that was used for the LCC analysis of conventional central air conditioner (CAC) product classes. Minor modifications were made to the spreadsheet model to incorporate inputs specific to SDHV products. The LCC model was developed using Microsoft Excel spreadsheets combined with Crystal Ball (a commercially available add-in). The LCC analysis models both the uncertainty and the variability in the model's inputs using Monte Carlo simulation and probability distributions. The LCC results are displayed as distributions of impacts compared to specified baseline conditions. Results are presented later and are based on 10,000 samples per Monte Carlo simulation run. The conventional CAC product LCC analysis and spreadsheet model are detailed in the *Residential Central Air Conditioner and Heat Pump Technical Support Document* (TSD) under Chapter 5, *Life-Cycle Cost and Payback Period Analysis*[1].

1.2 INPUTS TO LCC ANALYSIS

The LCC analysis for SDHV products utilizes the same inputs as those used in the LCC analysis conducted for conventional CAC products but with the following exceptions: 1) consumer equipment prices for baseline and standard-level SDHV products are based on a detailed engineering analysis conducted specifically for these products; 2) inclusion of an additional consumer price for the installation of the duct work; 3) electricity price trends are based on projections from the Annual Energy Outlook 2002 (*AEO2002*); and 4) repair costs are based on SDHV consumer equipment prices. All prices used in the SDHV LCC analysis are in 2001 dollars. Prices carried over from the conventional CAC product analysis to the SDHV analysis were converted from 1998 dollars to 2001 dollars using the annual consumer price indices (CPI) for all urban consumers[a] from the Bureau of Labor Statistics[2].

1.2.1 Baseline and Standard-Level Consumer Equipment Prices

Table 1.2.1 presents the *weighted-average* baseline and standard-level consumer equipment prices for SDHV products. Incremental equipment price increases due to an efficiency increase are actually characterized with normal probability distributions. Refer to the *Residential Central Air-Conditioner, Small Duct, High Velocity (SDHV) Systems Standards Rulemaking: Engineering Analysis* for more details. The consumer equipment prices were determined with markups and sales taxes different from those used for the conventional CAC product analysis. The prices in Table 1.2.1 are for the equipment only. The installation prices of the equipment and the duct work are not included.

---

[a] The 1998 and 2001 annual CPIs equal 163.0 and 177.1, respectively.

Table 1.2.1 Weighted-Average Baseline and Standard-Level SDHV Consumer Equipment Prices (2001$)

SEER	Incremental Price Increase	Total Consumer Equipment Price
10.0	-	$2,067
10.15	$26.35	$2,093
10.29	$52.70	$2,120
10.41	$79.05	$2,146
10.51	$105.40	$2,172
10.59	$131.75	$2,199
10.65	$158.10	$2,225
10.71	$184.45	$2,251
10.77	$210.80	$2,278
10.82	$237.15	$2,304
10.87	$263.50	$2,330
10.92	$289.85	$2,357
10.97	$316.20	$2,383
11.0	$325.76	$2,393
11.5	$431.16	$2,498
12.0	$668.31	$2,735
12.5	$835.25	$2,902
13.0	$1,072.40	$3,139
13.4	$1,283.20	$3,350

1.2.2 Duct Total Installed Cost

The total installed cost of the duct work was included in the SDHV LCC analysis. The total installed cost is the cost to the consumer of the labor and materials needed to install the duct work and was determined to be $2720. Refer to the *Engineering Analysis of SDHV Central Air-Conditioning Systems* for more details on how the installed cost for the duct work was determined.

1.2.3 Electricity Price Trend

In order to forecast electricity prices, a projected price trend in national average electricity prices is applied to each household's and commercial building's energy prices. The SDHV LCC analysis allows for the following scenarios to be analyzed:

- Constant energy prices
- Energy Information Administration *AEO 2002*, High Economic Growth[3]
- Energy Information Administration *AEO 2002*, Reference Case[4]
- Energy Information Administration *AEO 2002*, Low Economic Growth[5]
- Gas Research Institute (GRI) 1998 Baseline Projection[6]

Figure 1.2.1 shows the trends for the last four of the above projections. The values in later years (i.e. after 2015 for GRI and after 2020 for *AEO 2002*) are extrapolated from their relative sources. Extrapolation is needed because the sources used do not forecast beyond 2015 for GRI and 2020 for *AEO 2002*. For the *AEO 2002* trends, extrapolations are based on the average growth rate from 2010 to 2020. For the GRI trend, the extrapolation is based on the average growth rate from 2005 to 2015. LCC results presented later are based on the *AEO 2002* Reference Case price trend.

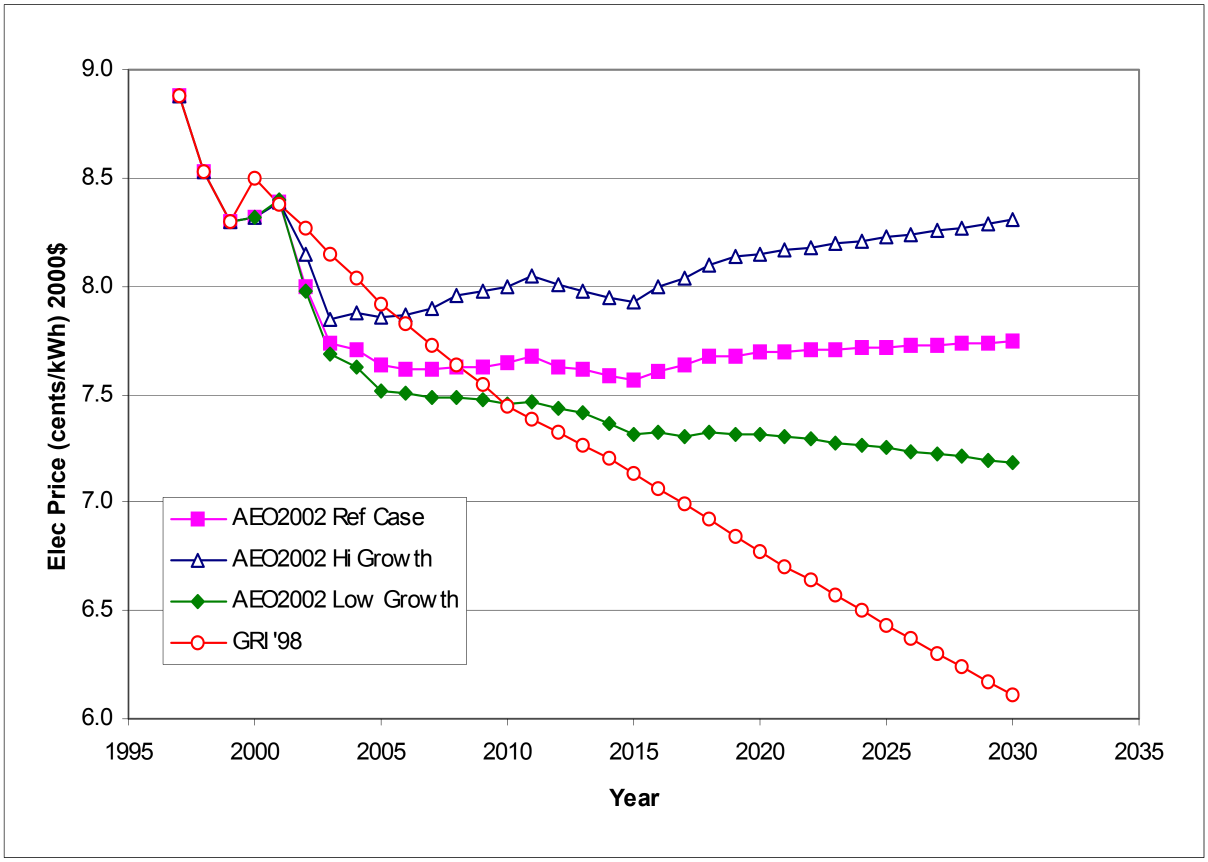

Figure 1.2.1 Electricity Price Trends

1.2.4 Repair Costs

The repair cost is the cost to the consumer for replacing or repairing components which have failed in the SDHV product. The assumed annualized repair cost for baseline (10 SEER) efficient SDHV products (i.e., the cost the consumer pays annually for repairing equipment) is based on the following expression:

$$RC = \frac{0.5 \cdot EQP}{LIFE}$$

Where,

RC = repair cost,

EQP = equipment price (consumer price for only the equipment), and

$LIFE$ = the average lifetime of the equipment (18.4 years).

If the efficiency of the condensing unit packaged with the SDHV unit has a seasonal energy efficiency ratio (SEER) rating of 13 or less, than the SDHV product is assumed to incur a one percent increase in repair cost over the baseline efficient equipment. If the condensing unit has an SEER rating greater than 13, the assumed annualized repair cost of the SDHV product is based on the equation presented above.

The rationale for assuming essentially flat repair costs for SDHV units that are coupled with condensing units that have efficiency ratings of up to and including 13 SEER pertains to the level of technology being used in the condensing units. For condensing units with ratings up through 13 SEER, system technology generally does not incorporate sophisticated electronic components which are believed to incur higher repair costs. Increases in condensing unit SEER are generally achieved through more efficient single-speed compressors or more efficient and/or larger heat exchanger coils. Condensing units with efficiencies beyond 13 SEER start to incorporate compressors which are generally believed to be more susceptible to failure.

Table 1.2.2 shows the *weighted-average* repair costs by standard-level. Since equipment prices are a function of variables which are represented by distributions rather than single point-values, repair costs are actually represented by a distribution of values rather than just the *weighted-average* values shown in Table 1.2.2.

Table 1.2.2 SDHV Weighted-Average Annualized Repair Costs (2001$)

SDHV SEER	**Annualized Repair Cost** [a]
10.0 through 10.99	$61
11.0 through 12.2	$62
greater than 13.4	$86

[a] SDHV SEERs of 10 to 10.99 based on 12 SEER condensing units; SDHV SEERs of 11 to12.13 based on 13 SEER condensing units; SDHV SEERs greater than 12.13 SEER based on 14 SEER condensing units.

1.2.5 Summary of Conventional CAC Product Weighted-Average Inputs

Table 1.2.3 lists the *weighted-average* values for the various LCC inputs (other than consumer equipment prices and repair costs) taken from the conventional CAC product analysis that are being used in the SDHV LCC analysis. Note that although the *weighted-average* values are being provided, for most inputs, probability distributions are used to characterize the input. The sections of the conventional CAC product TSD from which the data are being drawn are also presented in Table 1.2.3.

Table 1.2.3 Weighted-Average LCC Input Values taken from the Conventional CAC Product Analysis

LCC Input	Weighted-Average Value	Source
Percent of units used in commercial applications [a]	10%	CAC TSD, Section 5.1.4
Equipment Installation Cost (2001$)	$1390	CAC TSD, Section 5.2.2.8
Baseline (10 SEER) Energy Use (kWh/yr)[b]	Residential = 1947 Commercial = 5824 Combined = 2305	CAC TSD, Section 5.2.3.1
Average Electricity Price (cents/kWh)	Residential = 9.46 Commercial = 8.49 Combined = 9.36	CAC TSD, Section 5.2.3.5
Marginal Electricity Price (cents/kWh)	Residential = 9.16 Commercial = 8.64 Combined = 9.11	CAC TSD, Section 5.2.3.6
Maintenance Cost (2001$)	$40	CAC TSD, Section 5.2.3.9
Lifetime (years)	18.4	CAC TSD, Section 5.2.3.10
Compressor Replacement Cost (2001$)	10 - 10.99 SEER = $363[c] 11- 12.13 SEER = $391[d] >12.13 SEER = $498[e]	CAC TSD, Section 5.2.3.10
Discount Rate	5.6%	CAC TSD, Section 5.2.3.11

[a] Value is a single-point value.

[b] Standard-level energy use values are based on the ratio of the baseline efficiency (10 SEER) to the standard-level efficiency. Refer to TSD, Section 5.2.3.2 for more details.

[c] Range of SEERs based on 12 SEER condensing unit. As a result, 12 SEER conventional unit replacement cost is used.

[d] Range of SEERs based on 13 SEER condensing unit. As a result, 13 SEER conventional unit replacement cost is used.

[e] Range of SEERs based on 14 SEER condensing unit. As a result, 18 SEER conventional unit replacement cost is used.

1.3 LCC RESULTS

LCC results are presented here for the standard-levels specified in Table 1.2.1. Results presented here are based on the inputs described above. As has been discussed earlier, the value of most LCC inputs are uncertain and are represented by a distribution of values rather than a single point-value. Thus, the LCC results will also be a distribution of values.

1.3.1 Baseline LCC

As stated earlier, the Monte Carlo method of analysis relying on Crystal Ball (i.e., random sampling from distributions) was used to conduct the LCC analysis. The following results presented here are based on 10,000 samples per Monte Carlo run.

The first step in developing LCC results is to develop the baseline LCC. Figure 1.3.1 shows the frequency chart for the baseline LCC for SDHV products. A frequency chart shows the distribution of LCCs with its corresponding probability of occurrence. Table 1.3.1 summarizes the baseline distributions depicted in Figures 1.3.1 by showing the mean, median, minimum, and maximum LCCs.

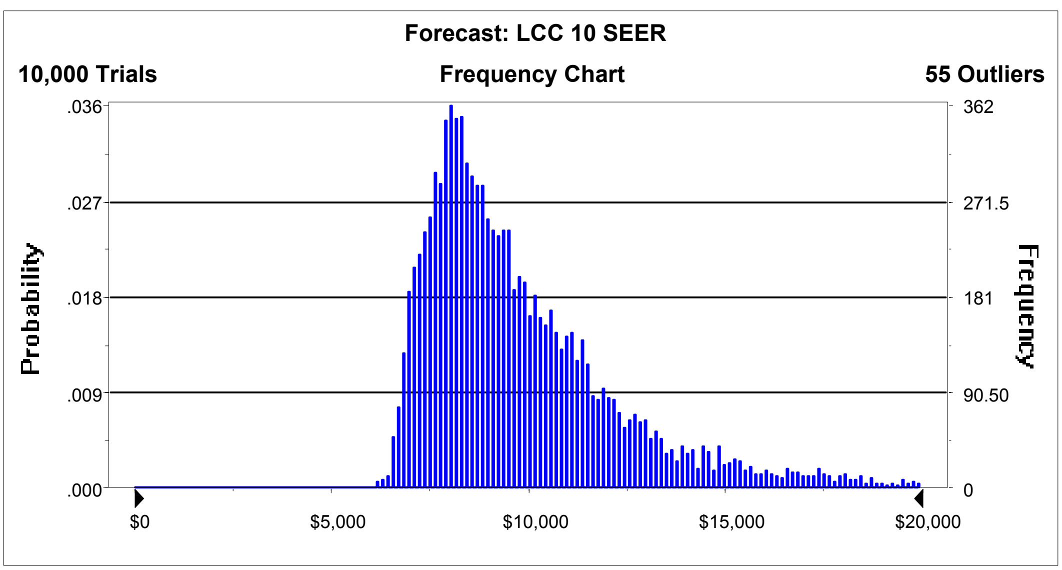

Figure 1.3.1 Baseline LCC Distribution

Table 1.3.1 Baseline LCC: Mean, Median, Minimum, and Maximum Values (2001$)

	Minimum	Median	Mean	Maximum
Baseline LCC	$6,160	$9,159	$9,843	$26,432

1.3.2 Change in LCC

The changes in LCC results are presented as differences in the LCC relative to the baseline central air conditioner or heat pump design. The LCC differences are depicted as a distribution of values. The primary results are presented in two types of charts within Crystal Ball: 1) a *frequency chart* showing the distribution of LCC differences with its corresponding probability of occurrence and 2) a *cumulative chart* showing the cumulative distribution of LCC differences along with the corresponding probability of occurrence. In each chart, the mean LCC difference is provided along with the percent of the population for which the LCC will decrease.

In the explanation below, the two charts depicting the case for an 10.51 SEER efficiency level are used (Figures 1.3.2 and 1.3.3). In either chart (frequency or cumulative), the mean change (reduction of $4 in the examples here) is shown in a text box next to a vertical line at that value on the x-axis. The phrase “Certainty is 35.41% from -Infinity to $0” means that 35.41 percent of households will have reduced LCC with the increased efficiency level compared to the baseline efficiency level (i.e., 10 SEER).

Figure 1.3.2 is an example of a *frequency chart*. The y-axes show the number of households ("Frequency" at right y-axis) and percent of all households ("Probability" at left y-axis). In this example, 10,000 households were examined ("10,000 trials") and all the almost all the results are displayed ("312 outliers"). The x-axis is the difference in LCC between a baseline efficiency level and a higher efficiency level (in this example, 10.51 SEER). The x-axis begins with negative values on the left, which indicate that standards for those households provide savings (reduced LCC). Reduced LCC occurs when reduced operating expenses more than compensate for increased purchase expense. In Figure 1.3.2, going from the baseline efficiency level (10 SEER) to the 10.51 SEER efficiency level provides buildings with an average LCC reduction of $6, and range from reductions of $300 (at the left) to increases of $126 (at the right) depending upon the building. (The minimum and maximum values cannot be read with precision from the graph, but rather, the program provides them in a statistical summary. It should be noted that in this example, reductions in LCC extend to $1285 but, because they are considered outliers, are not shown.)

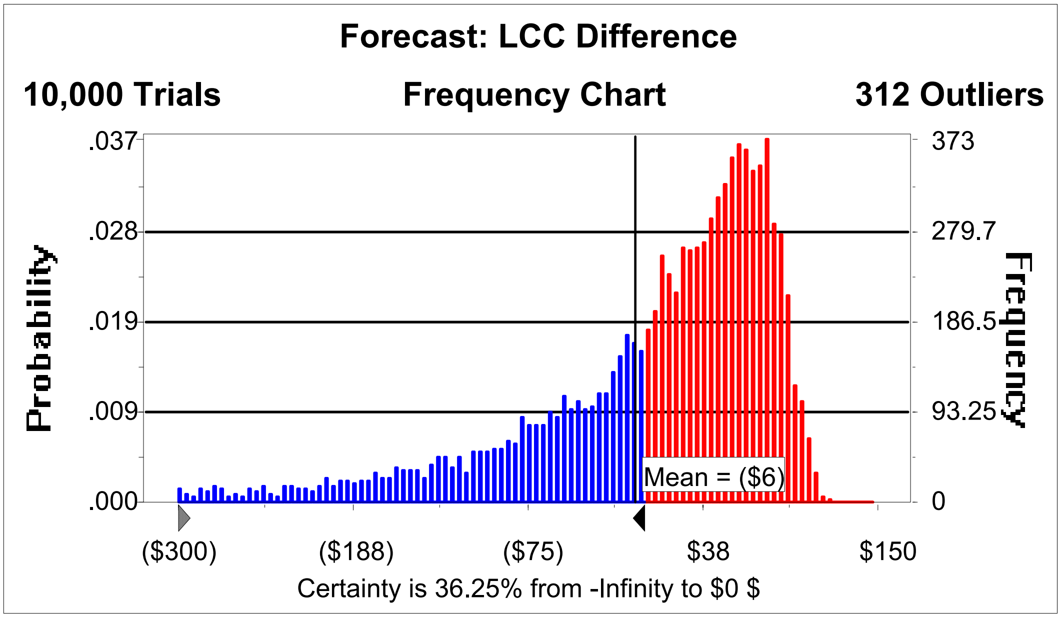

Figure 1.3.2 Frequency Chart of Differences for 10.51 SEER

The vertical axis in Figure 1.3.3 is the cumulative probability (left axis) or frequency (right axis) that the LCC difference will be less than the value on the horizontal axis. Starting at the left, there is a 0 percent probability that a household will have a reduction in LCC larger than $300 in absolute value (excluding outliers). At the right, there is a 100 percent probability that a household will have either a decrease in LCC or an increase in LCC of less than $126.

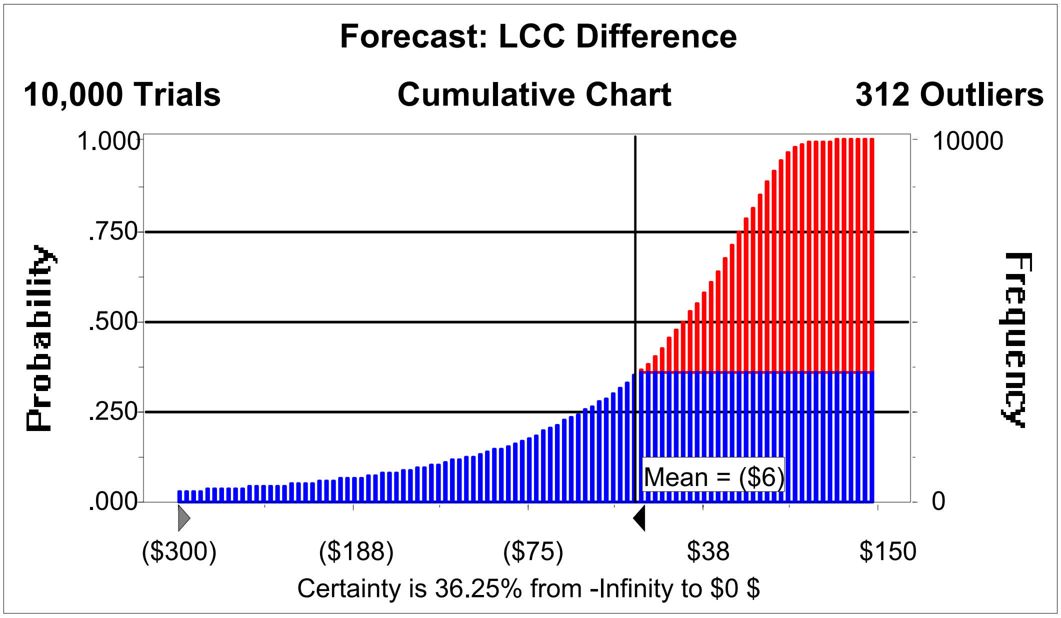

Figure 1.3.3 Cumulative Chart of LCC Differences for 10.51 SEER

A summary of the change in LCC from the baseline by percentile groupings (i.e., of the distribution of results) is provided below in Table 1.3.2. The mean and the percent of LCCs that are reduced for each standard-level are also shown. As an example of how to interpret the information in Table 1.3.2, the 10.51 SEER efficiency level is reviewed. The 10.51 SEER efficiency level in Table 1.3.2 (row 4) shows that the maximum (zero percentile column) change in LCC is savings of $1285. (Negative values are net savings.) For 90 percent of the cases studied (90th percentile), the change in LCC is a cost of $84 or less. The largest increase in LCC is $126 (100th percentile). The mean change in LCC is a net savings of $6. The last column shows that 36 percent of the sample have reduced LCC (i.e., change in LCC less than or equal to zero).

The results in Table 1.3.2 indicate that efficiency levels up through 10.51 SEER achieve mean LCC savings.

Table 1.3.2 Summary of LCC Results

	Change in LCC from Baseline Shown by Percentiles of the Distribution of Results (values in 2001$)												Percent of Buildings with reduced LCC
SEER	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**	**Mean**	
10.15	($331)	($49)	($25)	($12)	($3)	$3	$8	$12	$16	$20	$30	($8)	45%
10.29	($716)	($87)	($43)	($17)	($2)	$9	$18	$26	$33	$40	$61	($11)	42%
10.41	($1,206)	($115)	($53)	($19)	$2	$18	$32	$42	$52	$62	$91	($10)	38%
10.51	($1,285)	($139)	($60)	($17)	$10	$28	$45	$59	$71	$84	$126	($6)	36%
10.59	($1,242)	($149)	($59)	($11)	$21	$43	$61	$78	$93	$108	$158	$4	33%
10.65	($1,152)	($147)	($50)	$5	$37	$62	$82	$99	$115	$132	$191	$20	29%
10.71	($1,827)	($148)	($37)	$21	$56	$81	$103	$121	$139	$157	$219	$35	26%
10.77	($1,494)	($142)	($29)	$34	$71	$100	$121	$141	$161	$182	$256	$51	24%
10.82	($1,622)	($141)	($22)	$42	$87	$119	$143	$164	$184	$206	$282	$64	23%
10.87	($1,712	($133)	($4)	$62	$107	$137	$163	$186	$209	$233	$319	$83	21%
10.92	($1,536	($130)	$5	$75	$122	$157	$185	$209	$232	$256	$348	$98	19%
10.97	($1,928	($127)	$12	$86	$137	$176	$205	$231	$255	$282	$384	$115	19%
11.0	($2,426)	($102)	$43	$123	$170	$204	$233	$257	$280	$307	$406	$141	16%
11.5	($2,407)	($182)	$27	$131	$199	$248	$290	$326	$358	$396	$530	$161	18%
12.0	($3,440)	($150)	$130	$275	$367	$431	$487	$532	$578	$628	$837	$318	14%
12.5	($2,860)	$238	$533	$678	$773	$843	$908	$970	$1,048	$1,149	$1,648	$749	6%
13.0	($4,239)	$330	$681	$854	$968	$1,050	$1,116	$1,183	$1,261	$1,366	$1,843	$921	6%
13.4	($2,598)	$438	$824	$1,023	$1,140	$1,230	$1,309	$1,383	$1,466	$1,572	$2,175	$1,093	5%

1.3.3 LCC Results Based on ±2 Percent Threshold

The results in Table 1.3.3 show the percent of households with reduced LCC. But considering that the baseline LCC for each product class is significantly greater than the LCC differences shown in Tables 6, it is more useful to demonstrate which consumers experience significant net LCC savings or costs due to a higher standard-level. We define significant as those consumers experiencing net LCC savings or costs which are greater than 2 percent of the baseline LCC.[b] Since for SDHV products the *weighted-average* baseline LCC is $9843, this translates to an LCC increase or decrease of approximately $197 or an annual expense of approximately $10 over the lifetime of the system.

Table 1.3.3 depicts the LCC results based on the above defined 2 percent threshold. The tables show the average LCC values for the baseline level (10 SEER) and the various standard-levels analyzed. As presented earlier in Table 1.3.2, Table 1.3.3 also provides the difference in LCC at each efficiency level relative to the baseline. The differences represent either an LCC savings or an LCC cost increase. In addition, each table shows the subset of consumers (both residential and commercial) at each efficiency level who are impacted in one of three ways: consumers who achieve *significant* net LCC savings (i.e., LCC savings greater than 2 percent of the baseline LCC), consumers who are impacted in an insignificant manner by having either a small reduction or small increase in LCC (i.e., within ±2 percent of the baseline LCC), or consumers who achieve a *significant* net LCC increase (i.e., an LCC increase exceeding 2 percent of the baseline LCC). Accompanying each percentage value is the average LCC savings or increase that corresponds to each subset of consumers. For example, in the case of the 10.51 SEER efficiency level, the percentage of consumers with significant net savings is 6 percent and the corresponding average LCC savings for those consumers is $326. At 10.51 SEER, an

[b] The use of the ±2 percent threshold to express LCC results was used in the conventional CAC product analysis. Refer to section 5.2.4.4 of the conventional product CAC TSD.

overwhelming majority of the consumers (94 percent) are not impacted significantly by the efficiency increase. The efficiency level where a majority of consumers (52 percent) begin to incur significant LCC increases is 11 SEER.

Table 1.3.3 Summary of LCC Results based upon ±2 Percent Threshold criterion

SEER	Average LCC	Average LCC (Savings) or Costs (2001$)	Percent of Consumers with					
			Net Savings (>2%)	Average LCC (Savings) or Costs (2001$)	No significant impact (<2%)	Average LCC (Savings) or Costs (2001$)	Net Costs (>2%)	Average LCC (Savings) or Costs (2001$)
10.0	$9,843	-	-	-	-	-	-	-
10.15	$9,835	($8)	0%	($236)	100%	($8)	0%	-
10.29	$9,832	($11)	2%	($272)	98%	($5)	0%	-
10.41	$9,833	($10)	5%	($301)	95%	$5	0%	-
10.51	$9,837	($6)	6%	($326)	94%	$16	0%	-
10.59	$9,847	$4	7%	($342)	93%	$31	0%	-
10.65	$9,863	$20	7%	($352)	93%	$49	0%	-
10.71	$9,878	$35	8%	($370)	92%	$67	0%	$204
10.77	$9,894	$51	7%	($383)	88%	$77	5%	$211
10.82	$9,907	$64	8%	($395)	79%	$82	14%	$219
10.87	$9,926	$83	7%	($408)	67%	$81	25%	$229
10.92	$9,941	$98	8%	($424)	57%	$79	35%	$241
10.97	$9,958	$115	8%	($419)	50%	$74	43%	$255
11.0	$9,984	$141	7%	($444)	41%	$75	52%	$268
11.5	$10,004	$161	10%	($543)	30%	$58	60%	$325
12.0	$10,161	$318	9%	($624)	15%	$35	76%	$483
12.5	$10,592	$749	4%	($632)	5%	$30	91%	$852
13.0	$10,764	$921	4%	($718)	3%	$24	92%	$1,032
13.4	$10,936	$1,093	4%	($708)	3%	$19	93%	$1,202

1.4 REFERENCES

1. U.S. Department of Energy-Energy Efficiency & Renewable Energy, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps*, May 2002. Washington, DC. <http://www.eren.doe.gov/buildings/codes_standards/applbrf/central_air_conditioner.html>

2. U.S. Department of Labor, Bureau of Labor Statistics, *Consumer Price Index - All Urban Consumers (Current Series)*. Washington, DC. <www.bls.gov>

3. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2002*, December, 2001. Washington, DC. Report No. DOE/EIA-0383(2002).

4. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2002*, December, 2001. Washington, DC. Report No. DOE/EIA-0383(2002).

5. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2002*, December, 2001. Washington, DC. Report No. DOE/EIA-0383(2002).

6. Gas Research Institute, *1998 Edition of the GRI Baseline Projection*, 1998. Arlington, VA.